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TECHNICAL RESEARCH BY THE BUREAU OF MINES IN OIL AND GAS PRODUCTION, REFINING, AND UTILIZATION

BY

H. C. MILLER AND G. B. SHEA

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UNITED STATES DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

TECHNICAL RESEARCH BY THE BUREAU OF MINES IN OIL AND GAS PRODUCTION, REFINING, AND UTILIZATION[1]

By H. C. Miller[2] and G. B. Shea[3]

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INTRODUCTION

Several agencies of the Federal Government are engaged in research and fact finding relative to petroleum and natural gas, and others are concerned with carrying out the provisions of specific laws that affect these natural resources in their broad aspects. The Bureau of Mines, however, is the only Federal agency designated by law to engage in research in oil and natural-gas production, chemistry, refining, and

1/ The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from Bureau of Mines Information Circular 7173." This paper is one of a series on petroleum prepared at the request of the Energy Resources Committee of the National Resources Planning Board. Other papers in the series include Developments in the American Petroleum Industry, 1914-19, Exploration, Drilling, Production, and Transportation, by H. C. Fowler (Inf. Circ. 7171); Developments in Petroleum Refining Technology in the United States during 1914-19, by A. J. Kraemer (Inf. Circ. 7172); Gains in Oil and Gas Production, Refining, and Utilization Techniques, by H. C. Miller and G. B. Shea (published separately by the National Resources Planning Board as Tech. Paper No. 3, 1941). Work on manuscript completed June 1940.

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utilization. The Bureau of Mines carries out this direct mandate from Congress, which is a part of its organic act, through the Petroleum and Natural Gas Division, which studies technical problems of the industry, and through the Petroleum Economics Division, which, as the name implies, deals with statistical and economic subjects. Necessarily, there is a certain amount of advantageous dovetailing of activity within the two divisions, because few engineering problems are solved without giving proper weight to economic influences and many economic trends originate in engineering developments.

Both the technical and economic work of the Bureau of Mines on petroleum and natural gas originated in the Geological Survey. The separate organization of the Bureau grew out of the former Technological Branch of the Survey, and initially the old Division of Mineral Resources of the Survey collected and published petroleum and natural-gas statistics. Subsequently, this statistical work was consolidated in the Bureau of Mines. The discussion in this paper, however, deals mainly with the technical research on oil and natural gas as conducted by the Bureau of Mines.

To introduce this discussion adequately, cognizance is taken of the work of other Federal agencies, especially that of the Geological Survey, as their activities affect or relate to problems being studied by the Bureau, however, no attempt has been made to scrutinize closely and evaluate each project of the several other agencies. The following paragraphs show that there is little unnecessary duplication of effort or overlapping of activities.

Scientists of the Geological Survey, in cooperation with the American Petroleum Institute, are conducting fundamental research on the origin of petroleum through studies of composition and environment of source sediments. Geologic work of that type is entirely different from research pertaining to petroleum technology conducted by the Bureau of Mines. Petroleum engineers in the Land and Leasing Division, Conservation Branch, Geological Survey, from time to time study production methods and practices in the course of supervising oil and gas operations on public and Indian lands. Their specific findings, augmented by the results of research by the Bureau of Mines and the industry, are used to bring about better conservation measures on those lands. The work of this division, as distinguished from that of the Bureau of Mines, does not have for its main objective the collection and analysis of research data gathered over a wide field and assembled into form suitable for scientific and engineering reports for the general use of the industry and the public.

Where research of the Bureau has included studies on public and Indian land, the staff of the Oil and Gas Leasing Division of the Survey has been in a position to supply helpful technical information. When questions pertain to the geology and occurrence of oil and gas, Bureau of Mines engineers readily seek the benefit of the long experience of the Geological Survey along these lines. The results of a typical cooperative undertaking are given in a bulletin describing 104 oil and gas fields and favorable geologic structures in Wyoming.[4/]

4/ Espach, R. H., and Nichols, H. D., Petroleum and Natural Gas Fields of Wyoming: Bureau of Mines Bull. 418, 1941, 185 pp.

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The Navy Department, through the Bureau of Engineering, conducts research on certain phases of petroleum, but these studies are mainly for the Navy's own information; for example, the characteristics of lubricating oils and fuel oils are of special concern, as they affect movements of the fleet and auxiliary maritime and aircraft equipment. Technical information on a wide variety of petroleum subjects is furnished to both the Navy and the Army by the Bureau of Mines.

The National Bureau of Standards conducts petroleum investigations that pertain mainly to fuels and lubricants for internal-combustion engines and the testing of various petroleum products used in Government service and elsewhere. This Federal agency, in cooperation with the American Petroleum Institute, also is performing fundamental research relating to the separation of crude petroleum into its ultimate constituents and to underground corrosion of pipe lines and the corrosive action of soils. In the field of standardization, members of its staff have taken a leading part in establishing bases for the correct measurement of natural gas, the results of which have been used by Bureau of Mines engineers in their studies of the flow of natural gas through high-pressure transmission lines.

Other Federal agencies that deal with certain technologic or economic and statistical aspects of petroleum include the Petroleum Conservation Division of the Department of the Interior, Public Roads Administration, Bureau of Foreign and Domestic Commerce, Tariff Commission, Federal Trade Commission, and Bureau of the Census. The Bureau of Internal Revenue and the Bureau of Customs are concerned with the provisions of specific legislation pertaining to revenue from petroleum and its products. The Securities and Exchange Commission has been given authority by the Securities Act of 1933 and subsequent legislation to investigate and regulate the issuance of petroleum securities. The petroleum and natural-gas engineers of the Commission continually make use of the factual material in engineering and other technical reports of the Bureau to check and verify statements in registration applications and to estimate reserves of oil and gas in place.

Likewise, the Federal Power Commission is administering the provisions of a law (known as the Natural Gas Act of 1938) to regulate interstate transportation of natural gas. To determine and enforce shcedules made by pipe-line companies for interstate transportation of natural gas and reasonable wholesale rates for gas delivered at "city gates" (valves), engineers of the Federal Power Commission are called upon to estimate the natural-gas reserves in various fields, districts, and States. As the estimation of gas reserves has been a subject of research in the Bureau of Mines for many years, the fundamental background established in this engineering activity has been of great value to the engineers of the Federal Power Commission.

Virtually all Federal agencies have had occasion to use the results of technical research and statistical analyses of the Bureau of Mines. In turn, where such Federal agencies as the Geological Survey and the National Bureau of Standards have conducted technical research in certain phases of petroleum, Bureau of Mines engineers have advanced their own studies by using the applicable findings of those agencies.

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From the foregoing brief sketch it will be seen that a large part of the Government research on petroleum production, refining, and utilization is centered in the Bureau of Mines. In any detailed appraisal of the course and sufficiency of fundamental and applied studies by the Federal Government to the needs of the petroleum industry and the public, a review of the scope of the work and results obtained by the Petroleum and Natural Gas Division of the Bureau of Mines should be helpful. To that end the following sections are contributed.

INCEPTION OF TECHNICAL PETROLEUM RESEARCH BY FEDERAL GOVERNMENT

A suitable perspective by which to gage the accomplishments and present trends of technical petroleum research conducted by the Bureau of Mines can be established by looking backward to the act of March 3, 1879, creating the Geologic Survey. As stated, the Bureau of Mines was developed from the Survey's Technological Branch, and many recent engineering attainments may be traced to their nebulous source in concepts enunciated - sometimes only hinted - by early scientists of the Geological Survey.

Although the Geological Survey was established in 1879 to classify public lands and examine geologic structures and mineral resources of the national domain, Government interest in the conservation of oil and gas and in technologic research to extract greater quantities of these irreplaceable hydrocarbons from the natural reservoirs did not advance to where a moderately definite concept of Government responsibility could be formulated until shortly before the turn of the century. About that time, the slowly evolving thought that the continued welfare and progress of the United States depended on adequate supplies and wise use of the country's resources of oil and gas and other minerals began to find expression in the activities of the Geological Survey. Geologic investigations of the oil- and gas-producing regions of the United States and Alaska and of the conditions under which these hydrocarbons had been accumulated in them initiated studies aimed to assist oil producers to find new sources of oil and gas and to help them to understand conditions under which these important resources occur in underground formations. Almost from the beginning, studies of oil and gas by scientists in the Survey emphasized best practices for winning these hydrocarbons from nature's storehouse to the end that the minimum quantity would be left unrecovered when wells no longer could be operated profitably. The investigations also laid great stress on the more efficient utilization of petroleum, its products, and natural gas, to the end that the country's supplies be conserved for the longest possible time and for the benefit of the greatest number.

The first Geological Survey bulletin dealing with petroleum and natural gas[5] discussed geology, occurrence, and development in the Kansas-Indian Territory (Oklahoma) area. It included a preliminary report

5/ Adams, George I., Oil and Gas Fields of the Western Interior and Northern Texas Coal Measures and the Upper Cretaceous and Tertiary of the Western Gulf Coast: Geol. Survey Bull. 184, 1901, 62 pp.

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on the oil fields of an area extending from southern Arkansas through Texas and forming a belt in which lie Sherman, Dallas, Austin, and San Antonio. After describing the underground geology of the area, the author discussed the association of petroleum, sulfur, gypsum, and rock salt and concluded with a history of the early development of the Nacogdoches, Elgin and Lockhart, San Antonio, Sour Lake, and Beaumont oil fields of Texas. This report (published in 1901) expounded mainly the results of geologic studies and made no material contribution directly to research on oil and gas production. About that time, however, the Geological Survey began to give intensive thought and study to petroleum development and oil-production practices, as is evident from the increasing length of petroleum-technology discussions in subsequent publications.

In 1902 the second[6] of a long list of bulletins on oil and gas was published by the Geological Survey. In transmitting the manuscript of the report to Charles D. Walcott, then Director of the Geological Survey, C. Willard Hayes, geologist in charge of geology, wrote in part:

> I believe that this paper marks a distinct advance in the methods of studying oil fields and of determining and delineating the structure of oil-bearing formations. While it affords an exceptionally favorable opportunity for subjecting the anticlinal theory of oil and gas accumulation to a rigid test, its primary object is to furnish practical information to the well driller. If the data contained in the paper are properly used in the field, a saving in expense of development will be effected amounting to many times the cost of the work done by the Survey.

This report probably is the first published contribution made by a scientist employed by the Federal Government as a result of research on oil and gas development and production in which practical information was given whereby development costs could be reduced. Incidently, Hayes' letter of transmittal conveys one of the first official expressions of savings resulting to oil producers from the expenditure of smaller sums by the Government for scientific research on oil and gas.

In each succeeding publication of the Geological Survey wherein the results of its research activities on the geology of oil- and gas-bearing formations are explained, more discussion is given to production research. In a bulletin published in 1903, for example, Hayes and Kennedy[7] discuss not only the geologic characteristics of the Texas-Louisiana Coastal Plain but also the conditions for the accumulation of the oil, the general

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6/ Griswold, W. T., The Berea Grit Oil Sand in the Cadiz Quadrangle, Ohio: Geol. Survey Bull. 198, 1902, 42 pp.

7/ Hayes, C. W., and Kennedy, William, Oil Fields of the Texas-Louisiana Gulf Coastal Plain: Geol. Survey Bull. 212, 1903, 174 pp.

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characteristics of reservoir rocks, their porosity and saturation, and the mode of circulation of the saturating fluid through them. In addition, they discussed at some length the physical characteristics (color and odor, specific gravity, volatility, flash and burning points, and viscosity) and chemical properties (composition and constitution) of the oil, the causes of pressure in wells, and drilling methods.

Of particular interest to petroleum technologists and students of oil production is the section of the report entitled "Well Phenomena,"[8] in which the authors expound two theories (the hydrostatic theory and the gas-expansion theory) in explaining - probably for the first time - the pressure that causes oil and gas to gush from wells if not restrained. This section of the report is too long to be repeated here, but it is suggested that readers who are under the impression that present-day concepts of why oil wells flow are new consult the report and learn that theories promulgated 40 or more years ago represent today's accepted theories with remarkable accuracy.

It would not be feasible to record in chronologic order in this report the many early contributions by the Geological Survey to research on oil and gas production. Even a mere reference to the early work would be incomplete, however, without at least brief mention of the classic researches of King[9] and Slichter[10] on the movements of ground water. Although these studies (completed before 1899) had for their objective increasing knowledge of the motion of ground water in reservoir sands and rocks, many of the reported findings can be and within recentyears have been applied to oil-production problems. King,[11] for example, investigated not only the flow of water through sands but painstakingly carried on experiments on the flow of air through sands, sandstones, and other porous mediums. Thus, King not only established many fundamental concepts of great value to petroleum technologists but laid the groundwork for many experiments of a similar but more complex nature performed years later by engineers of the Bureau of Mines[12] and others studying the flow of air, natural gas, and oil through sands.

8/ Hayes, C. W., and Kennedy, William, Work cited in footnote 7/, p. 154.

9/ King, Franklin Hiram, Principles and Conditions of the Movements of Ground Water: Geol. Survey 19th Ann. Rept., 1899, pt. 2, pp. 59-294.

10/ Slichter, Charles S., Theoretical Investigation of the Motion of Ground Waters: Geol. Survey 19th Ann. Rept., 1899, pt. 2, pp. 295-384.

11/ King, Franklin Hiram, Work cited in footnote 9/, p. 157.

12/ Mills, R. van A., Chalmers, Joseph, and Desmond, J. S., Oil-recovery Investigations of the Petroleum Experiment Station of the Bureau of Mines: Am. Inst. Min. and Met. Eng., Tech. Pub. 144, 1928, 36 pp.

Chalmers, Joseph, Taliaferro, D. B. Jr., and Rawlins, E. L., Flow of Air and Gas through Porous Media: Am. Inst. Min. and Met. Eng., Petroleum Development and Technology, 1932, pp. 375-400.

Johnson, T. W., and Taliaferro, D. B. Jr., Flow of Air and Natural Gas through Porous Media: Bureau of Mines Tech. Paper 592, 1938, 55 pp.

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Slichter proved by experiments and mathematical calculations that the dynamic behavior of a liquid (water) when flowing in a radial system (as to wells through uniform reservoir sands) can be defined by an equation based upon a law promulgated by Darcy[13] almost half a century earlier for the linear flow of fluids through porous mediums. Petroleum engineers now recognize that the flow of a "dead" oil and gas, as well as water, through reservoir sands toward wells can be defined by an equation based on Darcy's law, and they use the relation in their determinations of the permeability of reservoir sands and rocks[14] and in solving many oil development and production problems.

During the first decade of the present century, however, the principal contribution of scientists employed by the Federal Government to technologic research in oil finding and production consisted of the systematic examination of land surfaces overlying oil and gas pools, geologic mapping, the interpretation of underground structures and conditions from well logs and records, and the sampling and analyzing of oils.

On May 16, 1910 (effective July 1, 1910), the Bureau of Mines was established in the Department of the Interior by an act of Congress (35 Stat. 369). After its organization the Bureau of Mines continued to analyze samples of petroleum - work begun in the Technological Branch of the Geological Survey. The Bureau also analyzed fuel oils used by the Government and initiated field studies, particularly in California, of wastes of oil and gas occurring on public lands and lands adjacent thereto. About that time, Bureau engineers began to study the use of cement to exclude water from oil and gas wells.

On July 1, 1914, the Petroleum Division of the Bureau of Mines became an officially recognized unit of the Bureau. With the exception of the latter part of 1917 and throughout 1918, when the activities of the Bureau of Mines on petroleum and natural gas were devoted mainly to problems of the World War, the studies of the Petroleum and Natural Gas Division have been concentrated almost entirely upon technologic investigations of petroleum and natural-gas production, refining, and utilization and (since July 1933) the extraction of helium from helium-bearing natural gases.[15]

During the administration of President Taft, a bill was passed (36 Stat. 847) providing for the withdrawal from public entry of large areas of possible oil- and gas-bearing lands. An outgrowth of these withdrawals

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13/ Darcy, H., Les Fontaines publique de la ville de Dijon (1856): Darcy-Basin, Recherches hydrauliques, Paris, 1865.

14/ Johnson, T. W., and Taliaferro, D. B., Jr., Work cited in footnote 12/, pp. 25-28.

15/ The helium work of the Bureau of Mines, begun as a wartime measure in 1917, was joined with that of the Petroleum and Natural-Gas Division in July 1933. For a brief historical sketch and other information on helium see Cattell, R. A., and others, Annual Report of the Petroleum and Natural-Gas Division, Fiscal Year 1939: Bureau of Mines Rept. of Investigations 3501, 1940, pp. 35-38.

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was the passage of the Mineral Leasing Act of February 25, 1920. Under this act, the supervision of operations under oil and gas leases on public lands became part of the duties of the Bureau of Mines. Among other important advancements in conservation of oil and gas, the Leasing Act

> ***established a definitely stated operating policy of the Government on these lands, as contained in the regulations governing the production of oil and gas. These regulations were prepared by the Bureau of Mines to prevent damage to the producing horizons and waste from them through specified methods which embodied the results of engineering studies of the Bureau and the best practices of the industry.16/

Supervision of oil and gas operations on public lands continued to be part of the duties of the Bureau of Mines until July 1, 1925, when all of these regulatory activities were transferred to the Land and Leasing Division, Conservation Branch, Geological Survey. Since then the Petroleum and Natural Gas Division of the Bureau of Mines has had the status solely of a research group, directing its efforts to solving specific technical problems and to developing information that can be disseminated widely for the purpose " * * * increasing safety, efficiency, economic development, and conserving resources through the prevention of waste * * * "17/ in the petroleum industry.

SCOPE OF BUREAU OF MINES RESEARCH AND FACILITIES FOR STUDY

The main function of the Petroleum and Natural Gas Division of the Bureau of Mines is to develop and carry out a coordinate system of research pertaining to the production, refining, and utilization of petroleum and natural gas. Fowler18/ aptly states how this is done:

> The best available knowledge and information regarding physical phenomena and other conditions are gathered together, and analyses are made of the data that help to explain the working out of definite laws and fundamental relationships. By the practical application of these relationships to oil and gas fields, pipe lines, and refineries, it is possible to produce oil and gas more rationally, transport them more efficiently, and manufacture them into useful products with less cost.

16/ Fowler, H. C., and Cattell, R. A., Influence of Petroleum Technology upon Composite Interest in Oil: Bureau of Mines Minerals Yearbook, 1935, p. 779.

17/ Part of section 2 of the amended organic act of the Bureau of Mines (37 Stat. 681), February 25, 1913.

18/ Fowler, H. C., Petroleum and Natural-Gas Studies of the United States Bureau of Mines: Bureau of Mines Inf. Circ. 6737, 1933, p. 2.

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Many studies by engineers and chemists of the division are fundamental and of the type that research workers in industry generally do not undertake because they do not seem to lead directly to the solution of immediate operating problems; others are of a "practical" nature and of immediate application, but, as stated by Cattell and others,19/ "insofar as possible both types of study are conducted and coordinated on the premise that to be effective they must have practical application eventually in the field or plant."

The Petroleum and Natural Gas Division of the Bureau of Mines maintains five field headquarters situated in major oil-producing areas in the United States. Despite the widespread geographical position of the division's two experiment stations (Bartlesville, Okla., and Laramie, Wyo.), a field office and laboratory at San Francisco, Calif., a field office at Dallas, Tex., and the laboratory at the Amarillo (Tex.) helium plant, the division operates as a closely knit unit. Although it is general knowledge that oil and gas occur in reservoir sands and rocks and are "captured" by drilling wells into the containing formations, the best method for producing these hydrocarbons in California, for example, may not be applicable to fields in Wyoming, Oklahoma, Texas, and other oil-producing States; nor will practices found to result in optimum extraction of oil and gas in eastern Kansas necessarily be equally efficient in the limestone areas of western Kansas. Accordingly, although fundamental research furnishes useful information for improving production methods and the efficiency of recovery in all areas where petroleum is extracted from reservoir sands and rocks, the manner in which the basic information is applied may differ materially from district to district. The successful application of fundamental information to practical problems requires intimate knowledge of field conditions in areas where improvements in production practices are desired.

The Bureau therefore endeavors to gain maximum benefits for the large section of the industry concerned with oil production which operates in 23 States and, through its organization of decentralized yet coordinated research, to obtain maximum results for the country at large. Moreover, the Bureau is in a favorable position to know and cope with the major problems of the producer in all parts of the country.

The staff of the Petroleum and Natural Gas Division comprises about 65 engineers and chemists (permanent employees) and a small force of mechanics and skilled laborers (exclusive of the operating and maintenance crew at the helium plant). The main petroleum experiment station is at Bartlesville, Okla. This station was established in 1918 upon a site containing 5 acres of land, and for 20 years the work at the station was conducted in two brick buildings and several temporary buildings erected shortly after the station was established. The industry's demands for increased work necessitated expanding the station facilities, and since 1937

19/ Cattell, R. A., and others, Annual Report of the Petroleum and Natural Gas Division, Fiscal Year 1939: Bureau of Mines Rept. of Investigations 3501, 1940, p. 5.

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research activities at the Bartlesville Station have been conducted in a new three-story office and laboratory building with a basement and two wings. The plant also includes an adjacent brick building and several of frame and sheet-metal construction. Facilities at the Bartlesville Station permit work on a wide range of producing and refining problems, including not only oil and gas investigations having particular reference to the petroleum industry of Oklahoma, for which that State has contributed generously with funds provided under a recurring cooperative agreement, but also problems having Nation-wide scope and application.

The Bureau's work at Laramie, Wyo., is carried on in a one-story office and laboratory building of concrete erected especially for the Bureau in 1935 by the University of Wyoming on the university campus. Important studies of black oils of Wyoming and other Rocky Mountain States are conducted at this station with the view of better utilizing these oils. One outlet is in the manufacture of suitable road-building materials. Problems of production relating specifically to various fields in Wyoming and adjacent States also are studied by engineers stationed at Laramie.

The San Francisco (Calif.) office was established in 1910 when the Bureau of Mines was organized, and it is the oldest field headquarters of the Bureau dealing with petroleum. This office and laboratory study technical problems pertaining to oil and gas that have special significance to the oil producers of the Pacific coast.

The Dallas (Tex.) office is headquarters for Bureau engineers conducting studies in oil fields of Texas, Louisiana, and Arkansas. These engineers also cooperate with engineers of the Bartlesville Station in studying field problems in Oklahoma. The office was established in 1920.

Since about 1935, the personnel of the former cryogenic laboratory of the Bureau of Mines helium plant at Amarillo, Tex., has been assigned to the solution of several petroleum and natural-gas problems that require knowledge of the behavior of substances at low temperatures and usually at high pressures. In addition, production engineers with headquarters at Amarillo are studying field problems in West Texas and New Mexico.

Cooperative Assistance

Many persons apparently have no clear understanding of the peculiar position of the Bureau of Mines as a fact-finding agency dealing with petroleum and natural-gas problems. Close and willing cooperation by the industry is essential to the success of the Bureau's program of research. A large part of this work is done in cooperation with individual companies, groups of companies, industrial organizations, trade associations, and various States and State agencies that supply either funds or facilities to aid in the experimentation. Some of the work is done pursuant to formal cooperative agreements between the Bureau of Mines and the cooperating agencies. Other activities are made possible by informal arrangements not covered by written agreements. The necessity for such procedure rests in the fact, long recognized by the Bureau, that to be effective the fundamental

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relationships established by laboratory experiments must have practical test and application. The correlation of laboratory findings with field experiences and the study of phenomena observed in the field by means of laboratory equipment, possible only through cooperation with the industry, permit solution of many oil- and gas-producing problems. The Bureau of Mines has no oil and gas wells, pipe lines, oil-storage tanks, or plants and refineries of its own for use in its research. The fact that companies are willing to interrupt or impede their own commercial operations to assist the Bureau's engineers and chemists in pursuing a course of technical investigation by permitting them to use such expensive equipment is definite indication that the industry considers work of this type worthy of incurring expenditure of funds or loss of immediate revenue to themselves.

Another reason for the support given by the industry has been cordial relations of the Bureau and the industry that have been maintained for nearly 30 years through strict adherence to the premise of unbiased appraisal of facts. When the Bureau began studying problems of petroleum and natural gas about 1910, the technical literature was very limited. During their travels from field to field and visits to plants, Bureau of Mines technologists made many friends in the industry because their observations on the shortcomings of then current practices and detailed published reports on methods and equipment judged to be most desirable were strictly on an engineering and economic basis without personal interest. In this way, a reputation for accurate analysis was established. Later the oil companies gradually built up their own engineering and technical staffs, and forums were organized in which to discuss technical subjects. Nevertheless the efficacy of permitting Bureau of Mines engineers to use company equipment had been proved, and the earlier practice still continues with mutual advantage.

Typical examples of work of the Bureau of Mines that would have been impossible except for the use of company facilities are studies of (1) evaporation losses of crude petroleum and gasoline from tanks, (2) losses caused by leakage from high-pressure natural-gas transmission lines, (3) subsurface conditions in oil and gas wells, and (4) safeguarding workmen at oil wells and in refineries. Augmenting these, a large number of publications of the Bureau of Mines on petroleum and natural gas - especially engineering field reports - contain in their acknowledgments a statement of company assistance, such as the following: "Many of the data presented were furnished through the courtesy of company officials, engineers, and geologists, and much credit is due them for their interest in the work and their valuable contributions." Probably no other research agency has been permitted to use so many facilities for conducting its studies, not owned or controlled by itself, or has been supplied with as extensive data for analysis as has the Bureau of Mines in its petroleum and natural-gas research. This condition is shown in the following section, which briefly reviews some of the more important activities on which relatively recent reports have been published or work is being done in accordance with the Bureau's current program of petroleum research.

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RECENT PROBLEMS AND CURRENT PROGRAM

Oil and Gas Production and Related Transportation

At present the Bureau's work on oil- and gas-production problems is placing major emphasis on the fluid and energy relations in petroleum reservoirs. The information is meager on fundamental relationships of oil and gas in reservoir sands and rocks, the mechanics of their flow to wells through the porous mediums in which they occur, and the energy relations involved in the various stages of flow from reservoir formations to the tanks at the surface. Accordingly, this program of research is aimed "to give the industry a better picture than it now has of the fluids and the energy in, or associated with, natural petroleum reservoirs and the way in which the available energy can be used to the greatest advantage in obtaining efficiency and optimum recovery."[20]

The general aims of fluid and energy studies are greater knowledge of the best methods of producing oil and gas; better ways for gaging and controlling wells that produce large quantities of gas in conjunction with relatively small quantities of oil; efficient production of "condensate"-type wells; optimum rates of recovery of oil and gas from wells and fields; efficient spacing of wells; and other desirable practices leading to maximum ultimate economic recovery of oil and gas from reservoir formations.

Some of the major studies conducted by the Bureau in its endeavor to increase the knowledge of fundamental relationships of oil and gas production and to increase efficiency of recovery of petroleum from reservoir sands and rocks pertain therefore to investigations of pressure and temperature in deep wells; gas-oil ratios of producing wells and fields and the effect on ultimate recovery of changes in volumes of gas produced with oil; collection and examination of subsurface samples of crude oil to determine data on saturation pressures; gas solubility and liberation, volumetric changes (shrinkage), thermal contraction, and changes in specific gravities of oils; physicochemical properties of natural hydrocarbon mixtures to obtain data that will afford bases for establishing relationships between such mixtures and fluids obtained at wellheads and in well bores with subsurface samplers; flow of air and gas through reservoir sands; function of water (natural and induced drive) in petroleum reservoirs in the production of oil; and permeabilities and porosities of oil-bearing sands and rocks. Other important studies relate to methods of taking cores of reservoir sands and bringing them to the surface of the ground under reservoir pressure for subsequent analysis in the laboratory; relations between permeability of oil-bearing formations and their productivity; well density (number of acres per well) and its influence on recovery efficiency; the influence of time of drilling and rate of production on ultimate recovery of oil; compaction of reservoir sands and rocks; and subsidence of the surface of the ground resulting from the withdrawal of oil and gas in some areas.

20/ Cattell, R. A., Memorandum regarding work of Petroleum and Natural Gas Division, Bureau of Mines, to members of that division, January 25, 1936.

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Problems other than those dealing directly with conditions in natural petroleum reservoirs, the characteristics and performance of producing formations, and the flow of the fluids through reservoir strata and up the well also are receiving warranted attention. Among these are field investigations of drilling and producing methods; studies of best practices to combat heaving shales in drilling for oil and gas; laboratory and field studies of mud fluids used in the drilling of wells; and investigations of methods for increasing the productivity of wells to the end that the efficiency of recovery of oil and gas from reservoir formations may be increased. Engineering studies of individual fields constitute a regular activity of the Bureau of Mines and are important adjuncts to its researches on various phases of oil and gas production. Several important field studies are in progress at present in Texas, Oklahoma, and other States. Petroleum engineers with headquarters at Amarillo are studying field problems in West Texas and New Mexico, where most of the oil production is from limestone formations and reservoir conditions are complicated and not of conventional types. The compressibility of gas also is being studied, also the prevention of "freezing" of high-pressure natural-gas transmission lines.

Development by Bureau of Mines engineers[21] of instruments and equipment for determining pressure and temperature in oil and gas wells has made possible the use of scientific methods for solving production problems, leading to more efficient methods of operations based upon conservation principles and to more equitable allocation of production in competitive fields, as well as in fields operating under a unit plan. For example, in 1932 special studies by Bureau engineers[22] on the operation of flowing wells and reservoir performance in the East Texas oil field first brought to the attention of the operators the minimum reservoir pressure necessary to operate the wells in that field by natural flow through flow strings of different sizes.

Recently, observations taken in a gas well in the Buffalo field, Texas, have been used successfully in studying underground leakage from the well into a "thief" formation.[23] This was probably the first pressure-temperature survey in a well to determine the source of underground leakage of gas. Steps were taken later by the operating company to correct the wasteful condition.

21/ Berwald, W. B., Buss, H. A., and Reistle, C. E., Jr., Bureau of Mines Multiple-diaphragm Recording Surface Pressure Gage: Bureau of Mines Rept. of Investigations 3291, 1935, 19 pp.

22/ Reistle, C. E., Jr., and Hayes, E. P., A Study of Subsurface Pressures and Temperatures in Flowing Wells in the East Texas Field, and Application of these Data to Reservoir and Vertical-Flow Problems: Bureau of Mines Rept. of Investigations 3211, 1933, 17 pp.

23/ Schellhardt, M. A., Dewees, E. J., and Barlow, M. H., Application of Well Test Data to the Study of a Specific Gas-Production Problem: Bureau of Mines Rept. of Investigations 3493, 1940, 22 pp. Abstract of paper presented before meeting of the Natural Gas Section, American Gas Assoc., Tulsa, Okla., May 8, 1939. (See Proc. Nat. Gas Sec., Am. Gas Assoc., 1939.)

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Methods for obtaining and analyzing subsurface samples of crude oil initiated by the Bureau in 1932[24] are used by its engineers and by company engineers throughout the producing industry to determine the energy relations involved in the various stages of flow from the reservoir formations to the tanks on the surface of the ground.[25] Recently the studies were extended to "condensate"-type reservoirs in which most of the hydrocarbons are in the gaseous state, and reports have been published dealing with this phase of Bureau work.[26]

Special laboratory equipment was developed by the Bureau to obtain data on mixtures of gases and liquids collected at wellheads that will afford bases for establishing relations between such mixtures and fluids obtained from well bores with subsurface samplers. The equipment includes an equilibrium cell for investigating the properties of fluids at pressures as high as 10,000 pounds per square inch and temperatures to 270° F. and a new photoelectric-relay, temperature-control unit. These are described and the results of tests made with them in determining the compressibility of gas from a field in Texas are discussed in a recent report.[27] The physical and chemical properties of petroleums and natural gases also are being studied by means of apparatus developed in the Amarillo laboratory for determining the compressibility of gases without volume measurements.[28]

24/ Lindsly, Ben E., A Study of "Bottom-hole" Samples of East Texas Crude Oil: Bureau of Mines Rept. of Investigations 3212, 1933, 22 pp.

25/ Lindsly, Ben E., A Bureau of Mines Study of a "Bottom-hole" Sample from the Crescent Pool, Oklahoma: Petrol. Eng., February-June (5 installments), 1936.
Hill, H. B., Rawlins, E. L., and Bopp, C. R., Engineering Report on Oklahoma City Oil Field, Oklahoma: Bureau of Mines Rept. of Investigations 3330, 1937, pp. 202-203.
Grandone, Peter, and Cook, Alton B., Collecting and Examining Subsurface Samples of Petroleum: Bureau of Mines Tech. Paper 629, 1941, 68 pp.

26/ Eilerts, C. K., and Schellhardt, M. A., Flow Characteristics, Composition, and Some Liquid-phase Properties of Hydrocarbon Fluids from a "Combination" Well: Bureau of Mines Rept. of Investigations 3402, 1938, 34 pp.
Eilerts, Kenneth, Smith, R. Vincent, and Cook, Alton B., Properties of a Petroleum-reservoir Liquid and Its Residua, with Application of the Data to Production Problems: Bureau of Mines Rept. of Investigations 3474, 1939, 32 pp.

27/ Eilerts, Kenneth, Smith, R. Vincent, and Wright, R. C., An Equilibrium Cell for Investigating Properties of Fluids from Petroleum and Natural-gas Reservoirs (With a Section on Hypothetical Phase Relations of Natural Hydrocarbon Mixtures): Bureau of Mines Rept. of Investigations 3514, 1940, 30 pp. (Abstract of paper presented before meeting of the Natural Gas Section, American Gas Assoc., in Tulsa, Okla., May 8, 1939. See Proc. Nat. Gas Sec., Am. Gas Assoc., 1939.)

28/ Burnett, E. S., Compressibility Determinations Without Volume Measurements: Presented at Semiannual Meeting, Am. Soc. Mech. Eng., Dallas, Tex., June 15 to 19, 1936. (See Jour. Appl. Mechanics, Dec. 2, 1936, pp. A136 - A140.)

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The function of edge water in the production of oil is receiving much-needed study by the Bureau, and through its efforts industry is being supplied with information showing that the natural water drive, if properly controlled, can reduce materially the quantity of oil left in reservoir sands when fields are abandoned. The laboratory work to date has been concentrated on determining the best rate of flow of water through sands for the maximum recovery of oil. A preliminary review[29] of published material on the generally accepted best rates of flow of edge water for recovery of maximum oil indicates that too slow an advance of water upward in oil-producing structures may leave a large percentage of oil unrecovered. It appears from studies made so far that there is an optimum rate of water advance which, if exceeded, will not increase materially the quantity of oil recovered from a sand, but at rates less than optimum the recovery efficiencies decrease as the rate of encroachment decreases. Inasmuch as conservation of petroleum demands the optimum rate of withdrawal of oil from fields, the importance of extending these studies is apparent.

For many years petroleum engineers in their studies of production efficiencies have been confronted by lack of data from which to gage the quantity of oil initially in a reservoir. In its East Texas studies,[30] the Bureau found that oil shrank while moving from the reservoir, where pressures are high, to surface tankage, where pressures are atmospheric, because gas escaped from solution in the oil as pressure declined. Inasmuch as 1 barrel of oil in the stock tanks may represent 1-1/4 or more barrels of oil in the reservoir (in extreme cases as much as 2-1/4 or more barrels), the shrinkage factor assumes major importance in estimating petroleum reserves and computing oil-recovery efficiences. If shrinkage is not considered, reserves will appear to be high and computed recovery efficiencies low.

For many years engineers expressed need for the development of a coring tool that would cut a core of the oil-bearing formation, seal the specimen, and bring it and the contained original fluids to the surface intact under reservoir pressure. Accordingly (soon after the subject had been discussed in the meeting of the Special Studies Committee on Well Spacing of the American Petroleum Institute in Colorado Springs in June 1937), a cooperative study covered by an agreement between the Institute and the Bureau of Mines was begun with the intention that Bureau engineers were to develop a pressure core barrel to be built by a commercial tool manufacturer and paid for by the Institute. A full-size experimental core barrel has been designed and constructed in accordance with the agreement. Although a number of cores have been cut successfully in deep wells and brought to the wellhead and to the laboratory under pressure, experimentation to improve the design, operation and efficiency of the core barrel is continuing. The major problem yet to

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29/ Miller, F. G., and Miller, H. C., Résumé of Problems Relating to Edgewater Encroachment in Oil Sands: Bureau of Mines Rept. of Investigations 3392, 1938, 18 pp.

30/ Lindsly, Ben E., Work cited in footnote 24, p. 15.

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be solved is to perfect means whereby cores can be cut under pressure without becoming contaminated by the fluids used in drilling. Bureau engineers, therefore, not only are improving the construction and operation of the pressure core barrel and developing methods for analyzing the cores recovered but also are concentrating studies on methods by which porous rocks under pressure can be cored without contamination by drilling fluids.31/

Recognizing that in dealing with fluid flow through reservoir sands and rocks the property of these mediums that allows fluid to flow through them is of major importance, Bureau engineers engaged in oil- and gas-production studies have been investigating the permeability and porosity of oil-bearing formations for several years. Experiments show32/ that accepted laws for flow of fluids through pipe lines cannot be applied to flow of fluids through porous mediums. Fluids flowing through a sand body seem to behave similarly to those flowing through a large number of conduits of different sizes, and from the data obtained on various conditions of flow, a general empirical equation has been developed to express the relationship for the flow of gas through porous mediums. Recently, the determination of the "connate" water content of oil-bearing formations has received the attention of Bureau engineers. Data on the porosity of reservoir sands and the degree to which the pores of the sand bodies are filled with water that in many reservoirs is so firmly trapped in the pore spaces that it does not flow with the oil to wells are important in calculating reserves and oil-recovery efficiencies.

The importance of optimum spacing of wells to recover oil from pools economically has long been recognized by Bureau engineers. More than 15 years ago a study of the relationship between oil recovery and well spacing led Cutler33/ to advance a tentative rule stating that under certain conditions doubling the distance between wells halves the ultimate recovery (of oil) per acre.

In view of the facts that production practices in general are not the same today as when Cutler made his study and that most wells now are not permitted to flow at maximum rates, Bureau engineers recently analyzed Cutler's 1924 report in the light of present-day methods of operating oil pools and published their conclusions.34/

The relationship between well spacing and oil recovery in both old and new pools continues to receive warranted attention by Bureau of Mines engineers. Old fields virtually exhausted of their recoverable oil are

31/ Taliaferro, D. B., and Heithecker, R. E., Bureau of Mines--A.P.I. Pressure Core Barrel (Progress Report on Its Design and Development): Bureau of Mines Rept. of Investigations 3481, 1939, 20 pp.

32/ Johnson, T. W., and Taliaferro, D. B., Work cited in footnote 12, pp. 29-48.

33/ Cutler, Willard W., Jr., Estimation of Underground Oil Reserves by Oil-Well Production Curves: Bureau of Mines Bull. 228, 1924, p. 89.

34/ Miller, H. C., and Higgins, R. V., Review of Cutler's Rule of Well Spacing: Bureau of Mines Rept. of Investigations 3479, 1939, 23 pp.

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studied so that the efficiency of former "wide-open" flow practices and close spacing may be compared with present practice, generally considered more efficient, of restricted flow and wider spacing of wells.

The report35/ of a study of acid treatment of wells drilled into limestone formations in Kansas shows that acid treatment usually increases the potential capacity of these wells to produce oil and thereby increases their "daily allowable" production, shortens the time needed to extract the recoverable oil, and increases the quantity of oil recovered ultimately from the reservoirs. The results of the study of acid treatment in Kansas are applicable, with suitable modifications, to other areas in which oil is produced from limestone formations.

One of the most intriguing problems met by engineers in estimating reserves and oil-recovery efficiencies is that of determining the original oil and gas content of limestone reservoirs. Such reservoirs vary widely in porosity, and wells drilled into them usually show wide differences in productivity characteristics, indicating erratic variations in porosity and permeability. Accordingly, Bureau of Mines engineers are studying the problem of estimating oil and gas reserves in limestone reservoirs of West Texas and New Mexico, and the data collected, on which a preliminary report has been published,36/ are being used to develop a method for estimating oil and gas reserves in limestone reservoirs.

Recent investigations of oil and gas transmission through pipe lines by the Bureau of Mines have been concentrated mainly on studies of the "freezing" of natural-gas pipe lines. Troubles caused by constrictions that form in gas-transmission lines during cold weather multiplied many-fold when lines were extended to distant gas-consuming centers, and operating pressures were increased to force the gas through them. The industry's desire that the Bureau of Mines study this gas-transmission problem took definite form in 1935 when the Bureau, in cooperation with the American Gas Association, initiated an investigation of freezing of natural-gas transmission lines. It was known at that time that the solids formed in the lines were not ice but compounds called gas hydrates and that ammonia had some effect as an inhibitor of their formation.

During the past 5 years Bureau engineers have studied the composition of gas hydrates, conditions under which they form, effectiveness of pressure reduction on their decomposition, and effectiveness of ammonia as an

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35/ Heithecker, R. E., Effect of Acid Treatment upon the Ultimate Recovery of Oil from Some Limestone Fields of Kansas: Bureau of Mines Rept. of Investigations 3445, 1938, 47 pp.

36/ Anderson, C. C., Hinson, H. H., and Schroeder, H. J., Reservoir Characteristics of the Eunice Oil Field, Lea County, N. Mex.: Bureau of Mines Rept. of Investigations 3456, 1939, 15 pp.

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inhibitor of hydrate formation. Progress reports[37] issued from time to time not only reveal the complexity of the investigation and its many ramifications but also give much practical information to natural-gas-transmission companies to aid them in solving this problem. The study is continuing, as there are many fundamental data to be determined before the results can be applied with certainty to all conditions of operation of gas-transmission lines.

Only a brief résumé of the many important investigations of oil and gas production and transportation that have been completed recently or are in progress can be given in a short report such as this. The annual report of the Petroleum and Natural-Gas Division[38] records in detail the studies made during the fiscal year 1939, and the research described therein (with the exception of one of two problems that have been completed since its publication) is continuing. The various types of experimental work on oil and gas production and transportation conducted at different field headquarters and the research on refining and utilization of oil and gas, discussed in the following section of this report, have the common objective of giving the industry, the public, and the Government information on the wise development and efficient use of the Nation's resources of oil and gas and the prevention of economic and physical waste of these important irreplaceable hydrocarbons.

Chemistry, Refining, and Utilization of Petroleum and Natural Gas

The Bureau's studies in petroleum chemistry and refining relate chiefly to the following:[39]

> ***more efficient utilization of petroleum through greater knowledge of its constitution and transformation into merchantable products. In conducting this part of its research, the Bureau has kept in mind future needs as well as immediate requirements. For many years, the Nation's need for motor fuels and other petroleum products has trended upward, and future availability of gasoline, regardless of source, is a part of the broad problem of conserving the petroleum resources of the country and delaying their inevitable depletion.

37/ Deaton, W. M., and Frost, E. M., Jr., Gas Hydrates in Natural-gas Pipe Lines: Proc. Nat. Gas Dept., Am. Gas Assoc., 1937, pp. 23-31; Am. Gas Assoc. Monthly, vol. 19, No. 6, June 1937, p. 219; Oil and Gas Jour., vol. 36, No. 1, May 20, 1937, p. 75; Gas Age-Record, vol. 80, No. 1, July 8, 1937, p. 37. Gas Hydrates: Proc. Nat. Gas Dept., Am. Gas Assoc., 1938, pp. 112-119; Gas Age, vol. 81, No. 11, May 26, 1938, pp. 33, 34, and 48; Gas, vol. 14, No. 6, June 1938, pp. 31-32. Field Practices Dealing with Gas Hydrates in Natural-gas Pipe Lines: Presented before the Natural Gas Section, Gas Assoc., Tulsa, Okla., May 8-11, 1939; Am. Gas Assoc. Monthly, September 1939, pp. 301-303, 326-327.

38/ Cattell, R. A., and others, work cited in footnote 19.

39/ Cattell, R. A., and others, work cited in footnote 19.

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The studies place emphasis on the chemistry and thermodynamics of refining oil rather than on specific refining processes. In general, the Bureau refrains from carrying out studies of specific refinery processes (except in very special assignments) because of the possibility of patent complications.

The Bureau recognizes the issues that doubtless would be involved if studies were made of particular processes, probably covered by patents or for which patent applications have been made, and concentrates its research on less-implicating problems of a fundamental nature but of Nation-wide scope; however, the Bureau avails itself of its close association with the industry to keep abreast of all important commercial developments in refining processes. This is possible because of the high esteem in which Bureau engineers and chemists are held and the assurance of the industry from past experience that the Bureau will not divulge confidential information. Consequently, the Bureau is able to study future as well as immediate needs of the industry.

As early as 1911 the Bureau of Mines recognized the value of determining physical and chemical properties of crude oils and their relative importance as sources of commercial products. Since that time crude oils from nearly all oil fields in the United States and from many foreign countries have been collected and analyzed, and as a result the Bureau has the most comprehensive collection of crude-oil samples and analyses ever assembled. As the work progressed, Bureau chemists developed a method of analysis[40] that makes possible comparison of different oils on a reproducible basis. Later they perfected a method of classifying[41] oils as to "base" that is a recognized standard for comparison. Considerable work also has been done on correlation indexes to aid in interpreting crude oil analyses[42] and a study has been made of the correlation between the characteristics of some crude oils and their geologic occurrence.

If the actual constitution of petroleum can be determined with greater accuracy, it should be possible to manufacture products more efficiently. As one approach to this end, chemists of the Bureau have been studying the molecular weights of petroleum fractions - especially viscous oils. The results of their continuing work using cryoscopic (freezing-point-lowering) methods have been reported.[43]

40/ Dean, E. W., Hill, H. H., Smith, N. A. C., and Jacobs, W. A., The Analytical Distillation of Petroleum and Its Products: Bureau of Mines Bull. 207, 1922, 60 pp.

41/ Smith, N. A. C., The Interpretation of Crude-oil Analyses: Bureau of Mines Rept. of Investigations 2806, 1927, 20 pp.
Lane, E. C., and Garton, E. L., "Base" of a Crude Oil: Bureau of Mines Rept. of Investigations 3279, 1935, 12 pp.

42/ Smith, H. M., Correlation Index to Aid in Interpreting Crude-oil Analyses: Bureau of Mines Tech. Paper 610, 1940, 34 pp.

43/ Rall, Harry T., and Smith, H. M., Physical and Chemical Properties of Petroleum Fractions: I. Behavior in Dilute Benzene Solutions: Ind. Eng. Chem., September 15, 1936, pp. 324-330. II. Relations Between Molecular Weight and Concentration in Dilute Solution: Ind. Eng. Chem., November 15, 1936, pp. 436-439. III. Handling Viscous Oils in Molecular Weight Studies: Ind. Eng. Chem., July 1939, pp. 387-390.

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Another part of the Bureau's research designed to increase knowledge of the composition of petroleum pertains to separation of its components--not necessarily as distinct compounds. Accordingly, special attention is being given to the fractionation of crude oil by distillation at atmospheric pressure,[44] vacuum distillations,[45] and the use of

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[44] A recent contribution to this work is Ward, C. C., A Review of the literature on the Construction, Operation, and Testing of Laboratory Fractionating Columns: Bureau of Mines Tech. Paper 600, 1939, 36 pp.

The Bureau's study of atmospheric distillation of petroleum has a background extending over the last 2 decades, some features of which are suggested by the titles of the following publications:

Wadsworth, J. M., Removal of the Lighter Hydrocarbons from Petroleum by Continuous Distillation: Bureau of Mines Bull. 162, 1919, 162 pp.

Dean, E. W., Hill, H. H., Smith, N. A. C., and Jacobs, W. A., The Analytical Distillation of Petroleum and Its Products: Bureau of Mines Bull. 207, 1922, 82 pp.

Cooke, M. B. and Rue, H. P., Studies in the Fractional Distillation of Crude Petroleum: Bureau of Mines Tech. Paper 431, 1928, 54 pp.

Rue, H. P., and Beall, I. N., A Study of the Crude Oil Produced in the Salt Creek Field, Wyoming: Bureau of Mines Tech. Paper 449, 1929, 27 pp.

Cooke, M. B., An Experimental Still for the Detailed Study of Crude Petroleum: Bureau of Mines Rept. of Investigations 2632, 1924, 21 pp.

Espach, Ralph H., A Visible-Action Continuous Distillation Apparatus for Laboratory Study of Fractionation: Bureau of Mines Rept. of Investigations 2892, 1928, 7 pp.

[45] The following publications represent types of work pertaining to vacuum distillation that have been reported:

Dean, E. W., Hill, H. H., Smith, N. A. C., and Jacobs, W. A., work cited in footnote 44.

Gavin, Martin, and Foster, Arch L., Apparatus for the Vacuum Distillation of Heavy Petroleum Oils: Bureau of Mines Rept. of Investigations 2996, 1930, 5 pp.

Guthrie, Boyd, and Higgins, Ralph, Laboratory Batch Still and Fractionating Column for Production and Study of Lubricating Distillates under Vacuum: Bureau of Mines Rept. of Investigations 3159, 1932, 18 pp.

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solvents.[46] From time to time studies also are made of the value of various properties of petroleum fractions, which are useful in determining the suitability of the crude oil for manufacture of lubricating oils, Diesel fuels, cracking stocks, and other products.

The problem of "sulfur-in-petroleum" has been of major importance to the petroleum industry since 1880, and one or more phases of this problem have been studied almost continuously by chemists and engineers of the Bureau of Mines since its organization. Some of the resulting reports have dealt with the fundamentals of occurrence, distribution, and identification of deleterious sulfur compounds, whereas others have described methods for removing sulfur from gasoline and light petroleum distillates.[47]

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[46] Results of the Bureau's early research on petroleum fractions by means of selective solvents have found practical application in the study and handling of rod waxes, wax distillates, and lubricating oils made by conventional refinery processes. The following publications are typical:

Reistle, C. E., Jr., Paraffin and Congealing-Oil Problems, with a chapter on a laboratory study of rod waxes, by C. E. Reistle, Jr. and O. C. Blade: Bureau of Mines Bull. 348, 1932, 171 pp.

Smith, H. M., Study of the Less-Volatile Oils in Salt Creek (Wyo.) Crude: Bureau of Mines Tech. Paper 428, 1928, 28 pp.

Smith, H. M., A Study of the Lubricant Fractions of Cabin Creek (W. Va.) Petroleum, with chapters on the Action of Solvents on Heavy Constituents of Petroleum: by F. W. Lane, I. H. Nelson, J. M. Devine, and H. M. Smith: Bureau of Mines Tech. Paper 477, 48 pp.

Horne, Joseph W., and Holliman, W. C., A Study of A Solvent Analytical Separation of Waxes from Petroleum and Its Lubricating Fractions: Bureau of Mines Tech. Paper 583, 1938, 16 pp.

[47] The following publications are representative of both types of work:

Sayers, R. R. and others, Investigations of Toxic Gases from Mexican and Other High-sulphur Petroleums and Products: Bureau of Mines Bull. 231, 1925, 108 pp.

Rue, H. P., and Espach, R. H., Refining of Light Petroleum Distillates: Bureau of Mines Bull. 333, 1930, 111 pp.

Allen, I. C., and Robertson, I. W., Methods of Determining the Sulphur Content of Fuels, Especially Petroleum Products: Bureau of Mines Tech. Paper 26, 1912, 13 pp.

Espach, R. H., and Rue, H. P., Influence of Fractionation of Distribution of Sulphur in Gasoline: Bureau of Mines Tech. Paper 505, 1931, 24 pp.

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47/ Continued-

Espach, R. H., and Blade, O. C., Studies on Determination of Sulphur in Gasoline: Bureau of Mines Tech. Paper 513, 1931, 22 pp.

Smith, N. A. C., and Stark, D. C., The Distribution of Sulphur in Crude Petroleum: Bureau of Mines Rept. of Investigations 2582, 1924, 17 pp.

Lane, F. W., and Devine, John M., The Detection of Sulphur in Petroleum and Petroleum Distillates: Bureau of Mines Rept. of Investigations 2828, 1927, 7 pp.

Kraemer, A. J., Lane, E. C., and Luce, C. S., The Sulphur Content of Commercial Motor Fuels: Bureau of Mines Rept. of Investigations 2843, 1927, 8 pp.

Rue, H. P., A Rapid Corrosion-Test for Gasoline: Bureau of Mines Rept. of Investigations 2862, 1928, 5 pp.

Devine, John M., and Lane, F. W., A Comparison of the Results Obtained with the Oxygen-bomb and Carius Methods in Determining Sulphur in the Heavier Petroleum Oils: Bureau of Mines Rept. of Investigations 2866, 1928, 3 pp.

Kraemer, A. J., A Survey of the Sulphur Content of Commercial Motor Fuels: Bureau of Mines Rept. of Investigations 3026, 1930, 11 pp.

Devine, J. M., and Wilhelm, C. J., Hydrogen Sulphide Content of the Gasin Some Producing Fields: Bureau of Mines Rept. of Investigations 3128, 1931, 15 pp.

Horne, J. W., and Shirey, W. B., Apparatus for Determination of Hydrogen Sulphide in Gas: Bureau of Mines Rept. of Investigations 3135, 1931, 6 pp.

Rue, H. P., Use of Lime in Salt Solution for Removing Hydrogen Sulphide from Natural Gas; Bureau of Mines Rept. of Investigations 3178, 1932, 8 pp.

Espach, Ralph H., Blade, O. C., and Rue, H. P., Removal of Free Sulfur from Gasoline by Lime and Hydrogen Sulfide: Ref. and Nat. Gasoline Manufacturer, vol. 13, No. 2, February 1934, pp. 65-69. (Reprinted).

The following publications exemplify Bureau of Mines reports on the prevention of hydrogen sulfide poisoning:

Sayers, R. R., Mitchell, C. W., and Yant, W. P. Hydrogen Sulphide as an Industrial Poison: Bureau of Mines Rept. of Investigations 2491, 1923, 6 pp.

Yant, W. P., and Fowler, H. C., Hydrogen Sulphide Poisoning in the Texas Panhandle, Big Lake (Tex.), and McCamey (Tex.) Oil Fields: Bureau of Mines Rept. of Investigations 2776, 1926, 20 pp.

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Special attention is being given to methods of refining high-sulfur or so-called "black" oils of the Rocky Mountain district that will result in reduction of the sulfur content of their commercial fractions. Investigations made to date have demonstrated that normal recoveries of desired products can be obtained fror Wyoming black oils by modern refinery methods, but the products so obtained still contain larger quantities of sulfur than trade specifications now in use permit;48/ however, research aiming to perfect means of reducing the sulfur content of the fractions of Wyoming black oils is continuing, and satisfactory progress is being made. With a decline in production of low-sulfur crude oils in Wyoming, the black oils doubtless will become increasingly important as sources of refined products to meet the requirements of the somewhat localized Rocky Mountain market. A solution of the "black-oil problem" leading to the adaptation of these oils to the needs of the day is therefore of potential economic significance.

The Bureau also is studying methods of increasing the usefulness of asphaltic crude oils from many fields of Wyoming and other Rocky Mountain States that are potential sources of asphalt. An important part of the problem is determining the essential properties of the asphalts and evaluating them in terms of suitability for specific uses.49/ This requires considerable fundamental research on the characteristics of asphalts, as many of the conventional tests, although used as a basis for specifications, give little perception of the fundamental characteristics of the product.

In connection with its refinery studies, the Bureau is making a survey of the adaptability of refineries to the processing of crude oils with the view of ascertaining, from a national economic standpoint and in the interest of conservation, the seasonal potential refining capacities of the various refining centers of the United States. As pointed out by Cattell and others,50/

47/ Continued -
Fowler, H. C., Prevention of Hydrogen Sulphide Poisoning in Handling and Refining High-sulphur Petroleums: Bureau of Mines Rept. of Investigations 2847, 1927, 27 pp.
Littlefield, J. B., Yant, W. P., and Berger, L. B., A Detector for Quantitative Estimation of Low Concentrations of Hydrogen Sulphide: Bureau of Mines Rept. of Investigations 3276, 1935, 13 pp.

48/ Thorne, H. M., and Murphy, Walter, A Survey of the High-sulphur Crude Oils (Black Oils) Produced in Wyoming: Bureau of Mines Tech. Paper 538, 1932, 56 pp.; Chemical and Refining Study of Some Wyoming Black Oils: Bureau of Mines Rept. of Investigations 3423, 1938, 39 pp.

49/ Stanfield, K. E., Some Asphalts from Oregon Basin (Wyo.) Crude Oil: Bureau of Mines Rept. of Investigations 3435, 1939, 17 pp.

50/ Cattell, R. A., and others, work cited in footnote 19.

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> Refinery adaptability is influenced not only by the complexity of the raw material (crude oil), as it affects the processing of different grades and types of oil, but also by seasonal demand for certain products such as gasoline, fuel oil, and furnace oils. Certain crude oils produced in Arkansas, for example, have a low gasoline content and are suited especially for the manufacture of petroleum asphalts, whereas other types of crude petroleum may yield relatively large percentages of motor fuels, lubricating oils, and furnace oils that require special refining equipment not needed where crude oils are "run" to asphalts.

Despite the progressive trend in preventing waste of natural gas in the production of oil, large volumes of natural gas still are blown to the air in many oil-producing areas, especially during their early development. Bureau engineers recognize the fallacy of producing excessive volumes of gas with the oil and for years have been searching for ways to reduce this waste. It is appreciated, however, that in many oil-producing areas, even those operated in accordance with accepted practices of efficient production, more gas will be produced with the oil than can be absorbed by existing markets. Bureau chemists, therefore, have studied some phases of the syntheses of motor fuels from natural gas by thermal decomposition (pyrolysis)51/ and have given considerable thought to the broad subject of the manufacture of chemical products from natural gas.52/

In addition to the more desirable light oil, considerable tar generally is formed in pyrolytic processes, and the economic utilization of byproduct pyrolytic tars has been the objective of intensive research by Bureau chemists.53/

Because of the dearth of information on the characteristics of different commercial gasolines marketed in summer and winter throughout the United States and the importance of this information to manufacturers and consumers, the Bureau has conducted periodic surveys of motor gasoline since 1915. Beginning in 1935 the collection of samples was simplified and the publication of results expedited through a cooperative agreement with the Cooperative Fuel Research Committee whereby gasoline-marketing companies in each of 20 or more marketing areas in the United States semiannually submit to the Bureau analyses of gasolines from service stations in their respective marketing areas. These reports are tabulated and published

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51/ Smith, H. M., Rall, H. T., and Grandone, Peter, The Production of Motor Fuels from Natural Gas. I. Preliminary Report on Pyrolysis of Methane: Bureau of Mines Rept. of Investigations 3143, 1931, 12 pp.

52/ Smith, Harold M., Utilization of Natural Gas for Chemical Products: Bureau of Mines Information Circ. 7108, 1940, 8 pp.

53/ Smith, H. M., Rall, H. T., and Grandone, Peter, Studies Pertaining to the Catalytic Hydrogenation of Pyrolytic Tars: Bureau of Mines Tech. Paper 587, 1937, 36 pp.

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twice each year by the Bureau to show the industry as well as consumers (without revealing the brand names of the reported motor fuels) a cross section of the variation in characteristics of gasoline in different grade and price classifications. These cooperative motor-gasoline surveys are based upon analyses of approximately 2,000 samples of gasoline.[54]

The Bureau is studying the use of liquefied petroleum gases with the view of better utilization. The steadily growing demand and increasing economic importance of propane, butane, and propane-butane mixtures produced as byproducts of cracking and natural-gasoline plants have changed the status of each of these hydrocarbons from a waste product to one of major importance. As a result of the need for more information on the transportation and storage of liquefied petroleum gases, these problems are being studied by the Bureau, and a report (particularly for the consumer) is being prepared on the use of propane and butane as domestic fuel.

Special Chemical and Engineering Research

Chemical and engineering problems requiring knowledge of petroleum characteristics and behavior comprise a special class of studies by the Bureau of Mines. Some of them pertain to all branches of the industry; others may appear first in plants or refineries and later in the field, as the study of the removal of salt from crude oil;[55] all of them touch upon the public interest in oil and affect the individual citizen directly or indirectly.

No more outstanding example of problems of this type may be found than the Bureau's practical research on evaporation losses of petroleum and its products. Wiggins and associates[56] called attention to these insidious losses and methods of preventing them by work begun in 1919. Since then timely mimeographed reports have been issued covering virtually all types

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54/ The first report under this agreement was issued as Report of Investigations 3311, Cooperative Fuel Research Motor-gasoline Survey, Winter 1935-36, by E. C. Lane and A. J. Kraemer. Thereafter E. C. Lane compiled the following: Summer 1936, Rept. of Investigations 3335; Winter 1936-37, Rept. of Investigations 3348; Summer 1937, Rept. of Investigations 3374; Winter 1937-38, Rept. of Investigations 3408; Summer 1938, Rept. of Investigations 3429; Winter 1938-39, Rept. of Investigations 3455; Summer 1939, Rept. of Investigations 3492; Winter 1939-40, Rept. of Investigations 3542; Summer 1940, Rept. of Investigations 3550; Winter 1940-41, Rept. of Investigations 3576.

55/ Christianson, L. F., and Horne, Joseph W., Desalting Crude Oil. A Review of the Literature: Bureau of Mines Rept. of Investigations 3422, 1938, 23 pp.

56/ Wiggins, J. H., Evaporation Losses of Petroleum in the Mid-Continent Field: Bureau of Mines Bull. 200, 1922, 115 pp.

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of tankage and stored petroleum liquids from the oil field to the gasoline bulk-storage plant. The individual reports of the series have been brought together in permanent form as printed publications.57/

The effects of another problem in this class actually reach the water taps in country kitchens and suburban homes. This condition results from contamination of otherwise potable water by brines produced with oil and gas. The Bureau's studies of the disposal of oil-field brines and petroleum wastes has helped to bring about a realization of the responsibilities that must be borne by oil and gas operators and refiners. Large sums are now being spent by the industry to protect water supplies, prevent excessive mineralization of surface streams that may injure farms and grazing lands and aquatic life, and provide for suitable disposal of petroleum wastes that may be detrimental to inland and coastal waterways. One of the chief results of the Bureau's research on this problem has been to show the necessity for returning oil-field brines to underground formations at reasonable cost and without detrimental effects. Much of this continuing work has been possible because of cordial relations with the operators and cooperative financial assistance given by interested States and State agencies concerned with public health. Nearly a dozen reports have been published on this subject during the past 5 years.58/

As described in detail in a companion paper of this series,59/ work of the Bureau of Mines from about 1914 to 1919 was largely instrumental in making the petroleum industry realize the importance of the correct use of cements and mud fluids in oil and gas wells to prevent waste. Research on these materials has turned to more fundamental aspects than were essential during the earlier period. For the past several years detailed studies have been made by Bureau engineers and chemists on the characteristics of mud fluids and the relationship of their properties to drilling technique in deep, high-pressure wells where the formations show a tendency to "heave" or slough into the well bore.

57/ Schmidt, Ludwig, Applied Methods and Equipment for Reducing Evaporation Losses of Petroleum and Gasoline: Bureau of Mines Bull. 379, 1934, 160 pp.
Schmidt, Ludwig, and Wilhelm, C. J., Reduction of Evaporation Losses from Gasoline Bulk-storage Stations, Bureau of Mines Tech. Paper 565, 1935, 35 pp.

58/ The following publications are typical:
Schmidt, Ludwig and Wilhelm, C. J., Disposal of Petroleum Wastes on Oil-producing Properties, with a chapter on Soils and Water Resources of Kansas Oil Areas, by Ogden. S. Jones. Bureau of Mines Rept. of Investigations 3394, 1938, 25 pp. (In cooperation with Kansas State Board of Health.)
Taylor, Sam S., Wilhelm, C. J., and Holliman, W. C., Typical Oil-field Brine Conditioning Systems; Preparing Brine for Subsurface Injection: Bureau of Mines Rept. of Investigations 3434, 1939, 71 pp.

59/ Fowler, H. C., Developments in the American Petroleum Industry, 1914-19; Exploration, Drilling, Production, and Transportation: Bureau of Mines Inf. Circ. 7171, 1941.

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With the completion recently of a comprehensive study of the causes of crude-oil emulsions and methods of reducing their formation,60/ engineers of the Bureau have begun a study of mechanical, hydraulic, and chemical methods of cleaning oil wells.

In addition to studies of the hazards of hydrogen sulfide poisoning incident to handling high-sulfur oils (see footnote 47/), the entire field of safety in the petroleum and natural-gas industry is open to exploration by Bureau engineers with their broad background of training in methods of preventing accidents. Typical recent reports review the accident experience of the petroleum industry of Oklahoma in 1937.61/

DISSEMINATION OF RESULTS

The results of Bureau of Mines research usually are made available through bulletins, technical papers, reports of investigations, and information circulars. In addition, special reports, some of which are classed as monographs, are published from time to time. Bureau engineers also are called upon frequently to present reports of their findings before meetings of technical societies -- the American Institute of Mining and Metallurgical Engineers, American Association of Petroleum Geologists, Natural Gas Association, American Petroleum Institute, and others. Thus, the assembled and analyzed factual information acquired during studies made by the Bureau of Mines is disseminated widely through Government publications, trade journals, proceedings of technical societies, correspondence, and interviews with the Bureau's technical staff. Judging from the large number of requests for Bureau publications, the rapidity with which many of them become "out of print," and the favorable comments of well-informed persons, the industry considers the work of the Bureau to be a definite help in guiding many of its operations.

To inform the many persons who are not technically concerned with the details of petroleum and natural-gas research yet have a definite interest in its effects, the Bureau of Mines takes part in visual-education activities. Its petroleum exhibits at various expositions have been a center of attraction, and motion-picture films on petroleum subjects are among the most popular in the Bureau's film library dealing with the mineral industries. These films are made through cooperative arrangement and "are loaned to educational institutions, engineering and scientific societies, civic and business associations, clubs, churches, and other responsible organizations."62/

60/ Shea, G. B., Practices and Methods of Preventing and Treating Crude-Oil Emulsions: Bureau of Mines Bull. 417, 1939, 106 pp.

61/ McCarroll, C. F., Accidents in the Petroleum Industry of Oklahoma in 1937 Summarized and Compared with 1923: Bureau of Mines Rept. of Investigations 3446, 1939, 19 pp.; Accidents in the Oklahoma Petroleum Industry in 1937: Bureau of Mines Tech. Paper 620, 1941, 141 pp.

62/ See latest list of Motion-Picture Films of the Bureau of Mines, January 1941, 31 pp.

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RESEARCH A CONTINUING PROBLEM

When an emergency arises it is too late to undertake research to discover better methods and practices for recovering oil and gas from nature's storehouse and the more efficient utilization of these irreplaceable hydrocarbons. Foreign countries without enough petroleum to meet their everyday needs for business and pleasure, not to mention extra requirements in time of war, have conducted research continually in oil-production methods and substitute materials. Even though no shortage of crude oil seems imminent in the United States at present, a glimpse at methods of increasing petroleum supplies both abroad and in this country may not be untimely before emphasizing types of research that are immediately necessary.

The U. S. S. R., for example, has conducted experiments to extract additional oil from reservoirs depleted of the oil that can be recovered by ordinary methods of production by gasifying the oil remaining in the sands. The object is to recover additional oil by condensing the petroleum vapors from the gases generated by heat in the reservoir.63/ To the writers' knowledge, no experimental work on gasification of oil in reservoir sands has been attempted in the United States.

Germany, after considerable experimentation, is mining the oil sands in the Wietze field in the Province of Hanover.64/ France tried mining the sands in the Pechelbronn field in Alsace and devised a method for recovering additional oil from the commercially depleted sands by sinking shafts and driving laterals from the shafts in the oil sands to drain them of oil.65/ Only a few attempts have been made to mine oil sands in the United States. The experimental workings include those at Sulphur Mountain, Ventura County, Calif.;66/ at Newport Beach, Orange County, Calif.;67/ in southwest Colorado near the Utah line, a few miles north of Fruita on Whiskey Creek;68/ and in the Jacksboro field, 75 miles northwest of Fort Worth, Tex.69/ None of these attempts proved profitable.70/

63/ Sheinman, A. B., Dubrovia, K. K., Sorokin, N. A., Charuigin, M. M., Aahs, S. L., and Zinchenko, K. E., (Gasification of Crude Oil in Reservoir Sands): Neftyance Khozyaistro, vol. 28, No. 4, April 1935 (in Russian). See translation in Petrol. Eng., pt. 1, December 1938, pp. 27-30; pt. 2, February 1939, pp. 91-100.

64/ Rice, George S., Mining Petroleum by Underground Methods: Bureau of Mines Bull. 351, 1932, p. 45.

65/ Rice, George S., work cited in footnote 64, p. 4.

66/ Uren, L. C., Oil Mining a Coming Practical Method of Secondary Production: Nat. Petrol. News, Oct. 5, 1927, p. 74.

67/ Crane, H., How California's Oil Mine at Newport Beach is Solving the Problem of Recovering Heavy Oil: Petrol. World, January 1926, p. 59.

68/ Rice, George S., work cited in footnote 64, p. 73.

69/ Smith, Lawrence E., Nat. Petrol. News, Nov. 5, 1924, p. 63.

70/ Miller, H. C., and Lindsly, Ben E., Report on Petroleum Development and Production: Petroleum Investigation, Hearings on H. Res. 441, 73d Cong. Recess 1934, pt. II, pp. 1210-1214.

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A method for mining oil sands in Pennsylvania was suggested by Ranney[71] in 1931, but to the writers' knowledge no practical application has been made of the suggested method. Recently Ranney proposed a new plan for recovering additional oil from sands that former methods of production have exhausted of their recoverable oil.[72] It involves sinking a circular shaft from the surface of the ground through the oil-bearing sand and drilling horizontal wells into the sand radially outward from the shaft. According to information supplied the writers by E. J. Dewees (Bureau of Mines, Bartlesville, Okla.), a shaft 36 feet in diameter has been sunk 38 feet near the outcrop of a commercially depleted oil sand in a field near Malta, Ohio. It was planned to drill 21 horizontal wells radially outward from the bottom of the shaft into the surrounding sand body.

For many years, Scotland has been extracting oil from shales and developing more efficient methods of operation. Other countries also have attempted to utilize their oil-shale deposits.[73] In the United States the Bureau of Mines began small-scale studies of oil shale and shale oil in 1916.[74] In 1924 a naval fuel-oil committee appointed by President Coolidge recommended that the Bureau study oil shale to determine the feasibility of using it as a source of fuel oil. An experimental oil-shale plant was built near Rulison, Colo., and during the next few years a great amount of technical information on the extraction of oil from shale was obtained.[75] Refining studies also were conducted at Boulder, Colo., and boiler-fuel tests were made by the Navy; however, the feasibility of using oil shale in the United States as a source of oil has not received enough study to permit the Nation's vast resources of oil shales to be used as a

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71/ Proc. Soc. Western Pennsylvania, vol. 47, No. 6, June 1931, p. 315.

72/ Ranney, Leo, The First Horizontal Oil Well: Petrol. Eng., June 1939. pp. 25-30. For more recent reports on this development, see articles by Ranney, Leo, Oil Weekly, Jan. 20, 1941, pp. 12-14, and Oil and Gas Jour., Jan. 23, 1941, p. 43.

73/ Gavin, M. J., Oil Shale, a Historical, Technical, and Economic Study: Bureau of Mines Bull. 210, 1924, 201 pp.
Institute of Petroleum, London, Oil Shale and Cannel Coal: Proceedings of a conference held in Scotland, June 1938, 476 pp.

74/ Gavin, M. J., work cited in footnote 73. The supply of some of the Bureau's early reports on oil shale and shale oil has been exhausted. To meet recurring requests, the Bureau had prepared in one bulletin a reprinting of the essential parts of the out-of-print publications together with previously unpublished material; see Guthrie, Boyd, Studies of Certain Properties of Oil Shale and Shale Oil: Bureau of Mines Bull. 415, 1938, 159 pp.

75/ Gavin, Martin J., and Desmond, J. S., Construction and Operation of the Bureau of Mines Experimental Oil-Shale Plant, 1925-27: Bureau of Mines Bull. 315, 1930, 154.
Kraemer, A. J., Oil Shale and Shale Oil: A Brief Review of the Work of the United States Bureau of Mines: Oil Shale and Cannel Coal: Proceedings of a conference of the Institute of Petroleum, London, held in Scotland, June 1938, pp. 227-247. (Reprinted.)

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source of oil upon short notice, and much remains to be done before oil-shale utilization can be established on a sound basis in the United States.

As there is at present no need in the United States for extracting oil from partly depleted reservoir sands by gasification and the urgency of using mining methods or retorting oil from shales has not been evident, research on these and other possible methods of extraction can be carried on more thoroughly than if the need for oil were great. When such work is undertaken, it should be incorporated into the Bureau's present program of research.

Experimental work of the type mentioned in the preceding paragraphs and many other problems needing solution suggested to the Bureau of Mines by the petroleum industry are so broad in scope that they should be performed by Federal research agencies. Individual oil companies cannot be expected to provide funds to prosecute extensive research of national benefit or to make public, perhaps for the benefit of competitors, the results of research sponsored and paid for by them.

The Bureau's list of "backlog" problems on which work cannot be begun owing to lack of funds and additional trained personnel indicates not only the need of the petroleum industry for more information on many oil-recovery and refining problems but also the industry's desire that Bureau engineers and chemists carry on the necessary research leading to their solution; however, for the Bureau to undertake more work than it is conducting at present (without additional funds to purchase supplies and equipment and to hire additional trained men) would necessitate "spreading too thin" the studies now in progress. Therefore, until the Bureau of Mines can expand the scope of its work on oil production and refining, research will have to be concentrated on the solution of the problems already begun and discussed in preceding sections of this report. The emphasis in production should be on reservoir performance and its applications to primary recovery of petroleum from deep-seated strata and to secondary recovery in older fields, using well-established stimulative methods. In chemistry and refining, the emphasis should be on the composition of crude oil and best use of its products to meet existing needs.

Petroleum Research as an Aid to Conservation

The conservation of oil and gas without needless waste as it affects the public interest of the United States and the exigency of national defense have stimulated Government concern in scientific investigations designed to extend the availability and usefulness of these important irreplaceable natural resources.[76] Moreover, as the owner of many thousands of acres of proved and potential oil land and the administrator

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76/ For a thorough discussion of the influence of technologic developments upon the public interest in oil see Fowler, H. C., and Cattell, R. A., Influence of Petroleum Technology upon Composite Interest in Oil: Bureau of Mines Minerals Yearbook, 1935, pp. 771-794.

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of oil- and gas-producing operations on large tracts of the public domain, the Federal Government has immediate vital interest in extended research aimed toward recovery of greater percentages of oil and gas from these hydrocarbon-bearing lands, more efficient utilization of oil and gas, and acquiring scientific information needed in its operation of petroleum properties.

So far petroleum geologists have been highly successful in finding new deposits of oil and gas and in increasing the country's reserves of these irreplaceable natural resources despite increasing annual production. If this record could be maintained as long as there is need for petroleum and its products, the leaving by the producer of 2, 3, 4, or more barrels of oil in the reservoir for every barrel of oil produced would be of no great concern. It is appreciated, however, that "although the oil resources of the United States are vast they are not unlimited, and* * *within a time that is short in the life of a Nation new reserves may no longer be found at rates now enjoyed."77/ As pointed out by Miller and Lindsly,78/ "geologists know the number of pools is definitely limited; their field of exploration narrows each year, and they are aware that each newly found pool leaves one less pool for later discovery." Furthermore, large areas in the United States are impossible, improbable, or unfavorable for the accumulation of petroleum, as shown by maps prepared by the Geological Survey, Department of the Interior. 79/

As large quantities of oil have been left in fields now depleted of their recoverable oil by known methods of economic recovery and as present methods of oil production (although for the most part recovering a greater percentage of the original oil than earlier practices) usually leave a large percentage of the original oil in the reservoir, now is the time to extend research studies aimed at increasing oil-recovery efficiencies. Recurrently the belief is expressed that when the Nation's oil reserves are

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77/ Miller, H. C., and Shea, G. B., Report on Recent Progress in Petroleum Development and Production: Petroleum Investigation, hearing on H. Res. 210 and H. R. 7372, 76th Cong., 1939, p. 324.

78/ Miller, H. C., and Lindsly, Ben E., Report on Petroleum Development and Production: Petroleum Investigation, hearings on H. Res. 441, 73d Cong. (Recess), 1934, pt. II, p. 1087.

79/ Map of the United States, showing oil fields and areas, now unproductive, classified with respect to their relative likelihood of yielding commercial quantities of oil, prepared by United States Geological Survey, 1934. Hearings before a Subcommittee of the Committee on Interstate and Foreign Commerce, House of Representatives, 73d Cong. (Recess) on H. Res. 441, pt. 2, fig. 1 (facing p. 910).

Map of the United States showing oil fields and unproductive areas classified with respect to their relative likelihood of yielding commercial quantities of oil, prepared by Geological Survey. Miser, H. D., Richardson, G. B., and Dane, C. H., Petroleum Reserves: Report of the Energy Resources Committee to the National Resources Committee, Energy Resources and National Policy, H. Doc. 160, 76th Cong., 1st sess., January 1939, Fig. 8, p. 293.

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exhausted by present methods of recovery, which are far from 100-percent efficient, petroleum substitutes will have been found that will make it unnecessary to extract much higher percentages of the oil from reservoirs than are now obtained. Those familiar with the petroleum situation in the United States and the problem of utilizing substitutes for petroleum on a scale comparable with present consumption of oil and gas agree, however, that some persons now living may witness the day when this country will find it necessary to extract the "last drop" of oil from oil-bearing reservoirs to carry on its normal peace-time business. From the standpoint of a strong national defense, so forcibly emphasized by present hostilities beyond this country's bordering oceans, the lack of knowledge resulting from inadequate governmental research in oil and gas production and utilization may prove a great handicap. The importance of petroleum in modern warfare can be pointed out no more forcibly than does Brier[80] in the following quotation:

> You can talk about food, you can talk about steel, about morale and generalship and propaganda, but the bedrock essential in conducting a war today is petroleum. It is so essential that if you haven't got it, you might as well consider pitting a Napoleonic battalion of musketeers against a machine-gun battalion.

Important as research is admitted to be as a means of extending the availability and utility of petroleum and natural gas, Federal appropriations for scientific exploration and dissemination of information on their production, refining, and utilization are far from adequate to assure the greatest usefulness in conserving the Nation's supplies of these resources. Studies of many fundamental problems, as well as those requiring the collection and analysis of available data without recourse to experimental work, could be projected, if funds were provided, with definite value to the industry, the consumer of petroleum and its products, and the Federal Government. The feeling is growing that the Government should assume a greater responsibility for carrying out a research program on a scale commensurate with the many problems of producing, storing, transporting, refining, and utilizing petroleum and natural gas. The conservation of natural resources is one field of natural science in which the Federal Government should take the lead. The Bureau of Mines is obligated by its organic act to conduct research in oil and gas technology, yet owing to the lack of a slight increase in funds it is unable to study adequately many problems needing immediate attention.

Virtually every private industry in the United States is expanding its research activities, and many of the larger oil companies have created research bodies within their organization because they know that the results of scientific studies pay large dividends; however, most producers and refiners of petroleum, other than the larger operators, are not financially able to undertake extensive research and therefore depend largely on the Government for the scientific information needed to conduct their

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80/ Brier, Royce, This World Today: San Francisco (Calif.) Chronicle, January 26, 1940, p. 1.

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commercial pursuits. On the whole, operators unable to conduct research outnumber those with facilities for making scientific investigations of oil production and refining techniques, yet these smaller companies and operators supply a large part of the Nation's petroleum--a very important reason why the Government should assume greater responsibility in furthering research on oil and gas as an aid to conservation.

In conclusion, the writers reiterate the opinion of the Secretaries of the Interior, War, Agriculture, Commerce, and Labor, and others of the National Resources Committee, as expressed to President Roosevelt in their letter transmitting a report entitled "Research--A National Resource":81/

> Research constitutes one of our most important resources* * *. If we are to make more effective use of all of the resources of the Nation for benefit of all of our citizens, our resources must be conserved and developed.

81/ Report of the Science Committee to the National Resources Committee, Research--A National Resource. I. Relation of the Federal Government to Research: Washington, December 1938, p. III.

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